Technical Notes and Implementation Hints for Quantum Computation as Phase-Engineered Vacuum Dynamics

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Abstract

This technical note provides a strictly operational companion to the article *"Quantum Computation as Phase-Engineered Vacuum Dynamics"*. Its sole purpose is to enable reproducible implementation, simulation, and experimental testing of phase-controlled Ψ-resonant dynamics.

Only minimal constraints, diagnostic criteria, and binary falsification conditions are specified. No new theoretical assumptions are introduced. No reinterpretation of quantum mechanics is proposed. All statements follow directly from the equations, bounds, and constructions established in the main article.

The note is written for experimental physicists, numerical modelers, control engineers, and simulation-oriented researchers. It is intended to prevent false negatives caused by incorrect implementations and to distinguish genuine Ψ-resonant behavior from generic nonlinear, thermal, or interference effects.

The scope is deliberately narrow: how to implement, how to test, and how to falsify.

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1 Purpose and scope of this technical note

This technical note provides **minimal implementation constraints, diagnostic checks, and failure discriminators** for reproducing the phase-controlled Ψ-resonant dynamics described in the main article *"Quantum Computation: Phase-Engineered Vacuum Dynamics"*.

The purpose is strictly operational:

- to enable **numerical and experimental reproduction**,
- to prevent **false negatives caused by incorrect implementations**,
- and to define **binary diagnostic outcomes**.

No new theory is introduced. No reinterpretation is added. All statements follow directly from the equations and bounds already established.

This note is addressed to experimentalists, numerical modelers, and control engineers.

2 Minimal dynamical system required

The Ψ-resonant behavior does **not** require a quantum simulation. A **classical nonlinear resonator** with coherent multi-port driving is sufficient.

Any of the following realizations are acceptable:

- Duffing oscillator with two coherent input ports,
- Kerr nonlinear cavity in input–output formalism,
- nonlinear Schrödinger envelope equation with coherent forcing.

The **minimal envelope equation** to implement is characterized by:

- single-mode approximation,
- weak Kerr (Duffing) nonlinearity,
- two coherent drives at the same frequency.

A canonical form is:

$$\frac{da}{dt} = \left(-i\Delta - \frac{\kappa}{2}\right) a - i\kappa_3 |a|^2 a + \sqrt{\kappa_1}\, s_1 + \sqrt{\kappa_2}\, s_2$$

where:

- $a(t)$ is the complex cavity envelope,
- $\Delta = \omega - \omega_\Psi$ is detuning,
- κ is the total linewidth,
- $\kappa_3 > 0$ is the Kerr nonlinearity,
- s_1, s_2 are coherent input amplitudes.

No quantization is required for observing bistability, phase-controlled switching, or non-additivity.

2.1 Mandatory parameter hierarchy

Correct behavior requires a **strict hierarchy of scales**.

The following inequalities must hold:

$$\omega_\Psi \gg \kappa \gg J \gg \Gamma_\varphi$$

and independently:

$$\kappa_3 A^2 \lesssim \kappa$$

Interpretation:

- ω_Ψ sets the carrier oscillation and must be the largest scale.
- κ sets the amplitude relaxation rate.
- J (or equivalent coupling rate) sets gate dynamics.
- Γ_φ sets coherence loss and must be the smallest scale.

Violating this hierarchy does **not** falsify the Ψ-framework, but it invalidates the qubit-level regime.

2.2 Constant total power condition (critical)

The defining experimental condition is **phase-only control at fixed total injected power**.

This condition is **not optional**.

The input amplitudes must satisfy:

$$|s_1| = |s_2| = s, \qquad P_{\text{tot}} = |s_1|^2 + |s_2|^2 = 2s^2 = \text{constant}$$

The **only control parameter** is the relative phase:

$$\Delta\phi = \phi_2 - \phi_1$$

All reported phase-dependent effects are invalid if:

- the total injected power drifts with $\Delta\phi$,
- amplitude and phase are swept simultaneously,
- or the drives are not phase-coherent.

A correct implementation must be able to verify experimentally or numerically that P_{tot} is constant during the phase sweep.

2.3 Effective coherent drive and interference

With symmetric coupling $\kappa_1 = \kappa_2 = \kappa_e$, the effective injected field is:

$$S(\Delta\phi) = 2\sqrt{\kappa_e}\, s \cos\left(\frac{\Delta\phi}{2}\right)$$

Therefore:

$$|S(\Delta\phi)|^2 \propto \cos^2\left(\frac{\Delta\phi}{2}\right)$$

This dependence is **purely interference-based**. No energy redistribution between ports is required.

This relation is the formal origin of phase-controlled switching at constant power.

3 What must be observed near resonance

When the system is tuned near $\Delta \approx 0$ and the nonlinearity satisfies the bistability condition, the following must be observed:

- two stable steady-state amplitudes A_- and A_+,
- hysteresis when $\Delta\phi$ is swept adiabatically,
- switching between A_- and A_+ controlled solely by $\Delta\phi$.

These effects must:

- disappear off resonance,
- disappear when $\kappa_3 \to 0$,
- disappear under incoherent drives.

Any observation violating these conditions is not evidence of Ψ-resonant dynamics.

4 What does not count as validation

The following do **not** constitute validation:

- switching driven by amplitude modulation,
- switching persisting far from resonance,
- effects reproduced with incoherent sources,
- broadband nonlinear response independent of phase,
- thermal or Joule-heating-dominated hysteresis.

Such effects indicate generic nonlinearity, not phase-engineered dynamics.

5 Numerical implementation notes (minimal)

For numerical simulations:

- time step: $\Delta t \ll 1/\kappa$,
- integrator: Runge–Kutta (RK4) or stochastic Heun if noise is included,
- initialization: always start from a steady solution,
- phase sweep: must be adiabatic with respect to κ^{-1}.

A common numerical error is reinitializing the state at each phase step, which destroys hysteresis by construction.

6 Noise sensitivity (diagnostic)

Phase noise enters exclusively through $\Delta\phi(t)$:

$$\Delta\phi(t) = \Delta\phi_0 + \xi_\phi(t)$$

Correct behavior requires:

- dephasing rate Γ_φ proportional to injected phase noise strength,
- weak dependence on mobility or scattering parameters.

If decoherence does not scale with phase noise, the Ψ-resonant regime is not realized.

7 Scope of validity

This implementation note applies only when:

- a single or few modes dominate,
- bistability exists,
- phase coherence is preserved over multiple κ^{-1} times.

Outside this domain, the system transitions naturally to continuous-variable dynamics, which is not a failure of the underlying Ψ-field model.

8 Resonant non-additivity: precise implementation

Resonant non-additivity is the **second non-negotiable diagnostic** after phase-only switching.

The observable is defined operationally as:

$$\Delta R(\omega, \Delta\phi) = R_{12}(\omega, \Delta\phi) - [R_1(\omega) + R_2(\omega)]$$

where:

- R_1 is the response with port 1 only,
- R_2 is the response with port 2 only,
- R_{12} is the response with both ports coherently driven,
- total injected power is held constant across all measurements.

The key requirement is **identical power normalization** in all three cases.
Any deviation from equal total injected power invalidates the diagnostic.

9 Frequency localization requirement

The non-additive response ΔR must satisfy all of the following:

- $\Delta R \neq 0$ only in a narrow frequency window around ω_Ψ,
- $\Delta R \to 0$ as $|\omega - \omega_\Psi| \gg \kappa$,
- the width of the ΔR peak scales with κ.

Any of the following observations invalidates the interpretation:

- broadband ΔR,
- ΔR persisting far from resonance,
- ΔR independent of $\Delta\phi$.

This condition excludes generic electronic, thermal, or transport nonlinearities.

10 Phase dependence structure

At fixed $\omega \approx \omega_\Psi$, the expected structure is:

$$\Delta R(\Delta\phi) \propto A^2(\Delta\phi) - \left(A_1^2 + A_2^2\right)$$

where $A(\Delta\phi)$ is determined implicitly by the bistability equation of the driven nonlinear mode.

Qualitatively:

- ΔR is maximal near $\Delta\phi \approx 0$,
- $\Delta R \to 0$ near $\Delta\phi \approx \pi$,
- sharp transitions appear near the phase-controlled switching thresholds.

Smooth sinusoidal modulation without hysteresis indicates linear interference, not Ψ-resonant bistability.

11 Control experiment hierarchy (strict order)

Control experiments must be performed in the following order. They are **not interchangeable**.

11.1 Incoherent drives

- Replace the splitter with independent, uncorrelated sources.
- All phase-dependent effects must vanish.

Persistence of switching or non-additivity under incoherent drives invalidates the implementation.

11.2 Linear regime

- Reduce drive amplitude until $\kappa_3 A^2 \ll \kappa$.
- Bistability must disappear.
- ΔR must vanish identically.

If non-additivity persists in the linear regime, the observed effect is not Ψ-resonant.

11.3 Asymmetric coupling

- Set $\kappa_1 \neq \kappa_2$ deliberately.
- Switching thresholds shift according to the interference formula.
- Phase effects persist but lose symmetry.

Failure of this asymmetry test indicates incorrect modeling of the drive geometry.

12 Minimal experimental checklist (binary)

An implementation is valid only if **all** items below are satisfied:

- ☐ Geometry-controlled resonance frequency ω_Ψ
- ☐ Independently verified weak Kerr nonlinearity ($\kappa_3 > 0$)
- ☐ Two coherent, phase-locked input ports
- ☐ Constant total injected power
- ☐ Phase-controlled switching near resonance
- ☐ Resonant non-additivity
- ☐ Decoherence dominated by injected phase noise
- ☐ All negative controls passed

This checklist is deliberately binary. Partial success has no interpretive value.

13 Typical implementation mistakes (observed in practice)

The following errors are common and lead to false negatives:

- sweeping phase and amplitude together,
- normalizing each measurement independently,
- using spectrum analyzers without a phase reference,
- reinitializing simulations at each phase point,
- interpreting thermal hysteresis as bistability,
- neglecting off-resonance baselines.

None of these failures contradict the framework. They invalidate the test, not the model.

14 Why this note exists

The Ψ-resonant effect is subtle **by construction**:

- it is not an energy effect,
- it is not a transport effect,
- it is not a materials effect.

It is a **phase–geometry effect**.

Standard intuition from electronics and nonlinear transport is therefore unreliable unless the constraints above are enforced exactly.

15 Minimal falsification restated (operational)

If, under the simultaneous conditions of:

- independently verified weak nonlinearity,
- constant total injected power,
- coherent phase control,
- near-resonant operation,

no phase-dependent switching and no resonant non-additivity are observed, then the Ψ-resonant implementation hypothesis fails within its stated scope.

No auxiliary interpretation is required. No parameter tuning rescues a negative outcome under these constraints.

16 Minimal reproduction recipe (hardware-agnostic)

This is the **shortest reproducible path** from zero to a decisive result.

16.1 Preconditions

- A single resonant mode must be clearly identifiable.
- A weak but measurable Kerr nonlinearity must be present (frequency shift with amplitude).
- Two coherent signals with controllable relative phase must be injectable.

If any of these is missing, stop. Do not proceed.

16.2 Linear characterization

- Drive the system using a single port.
- Measure the resonance frequency ω_Ψ and linewidth κ.
- Verify stability and absence of hysteresis at low power.

This establishes the linear baseline.

16.3 Nonlinearity verification

- Increase drive power slowly using a single port.
- Measure the resonance shift $\delta\omega(A)$.
- Confirm Duffing-like behavior: $\delta\omega \propto A^2$.

Bistability is not required at this stage. Only verify that $\kappa_3 > 0$.

16.4 Two-port coherent setup

- Split a single source into two arms.
- Insert a phase shifter in one arm.
- Match amplitudes such that $|s_1| = |s_2|$.
- Lock the phase reference.

Do **not** renormalize power at each phase point.

16.5 Constant-power phase sweep

- Fix $\omega \approx \omega_\Psi$.
- Fix total injected power $P_{\text{tot}} = |s_1|^2 + |s_2|^2$.
- Sweep $\Delta\phi \in [0, 2\pi]$.
- Measure the response $R(\Delta\phi)$.

Expected behavior:

- no effect at low power,
- bistability and hysteresis near resonance above threshold,
- switching controlled by phase alone.

If switching requires changing power, stop.

16.6 Non-additivity test

Measure:

- $R_1(\omega)$ with port 1 only,
- $R_2(\omega)$ with port 2 only,
- $R_{12}(\omega, \Delta\phi)$ with both ports coherently driven.

Compute:

$$\Delta R = R_{12} - (R_1 + R_2)$$

Repeat for multiple frequencies.
Expected:

- $\Delta R \neq 0$ only near ω_Ψ,
- $\Delta R \to 0$ off resonance,
- ΔR depends on $\Delta\phi$.

16.7 Phase-noise injection

- Inject controlled phase noise with known diffusion constant D_ϕ.
- Measure a coherence proxy decay.
- Verify $\Gamma_\varphi \propto D_\phi$.

If decoherence is insensitive to phase noise, the architecture is not phase-dominated.

17 Minimal numerical simulation (sanity check)

A correct simulation requires **no quantum formalism**.

The minimal model consists of:

- a single nonlinear oscillator,
- two coherent drives with fixed total power,
- a slowly varying relative phase.

The core equation is:

$$\dot{a} = (-i\Delta - \kappa/2)a - i\kappa_3|a|^2 a + \sqrt{\kappa_1}s\, e^{i\phi_1} + \sqrt{\kappa_2}s\, e^{i\phi_2}$$

Key rules:

- Do not reinitialize a at each phase value.
- Integrate continuously in time.
- Sweep $\Delta\phi$ adiabatically.

If hysteresis appears in simulation but not in experiment, the issue is experimental. If it appears in neither, the hypothesis fails.

18 What not to expect

Do not expect:

- discrete particles,
- charge transport signatures,
- quantized currents,
- exotic material effects,
- violations of standard quantum mechanics.

This framework produces no spectacular signals. It produces clean phase behavior under strict conditions.

19 Scope reminder

This technical note claims only:

- how to implement,
- how to test,
- how to falsify.

It does not claim:

- universality beyond demonstrated regimes,
- superiority over existing platforms,
- immediate scalability.

Anything beyond this is future work.

20 Closure of the technical note

At this point, the framework reduces to a single experimental question:

> Can a weakly nonlinear resonant system exhibit phase-only controlled state selection at constant total power, localized to resonance, with decoherence dominated by phase noise?

Yes $\rightarrow$ the Ψ-resonant implementation exists. No $\rightarrow$ it does not.
No intermediate interpretation is logically consistent.

A Appendix A Equations-only cheat sheet

This appendix collects the minimal set of equations required to implement, simulate, diagnose, and falsify phase-controlled Ψ-resonant dynamics.

No interpretation is included. No derivations are repeated.

A.1 Field envelope dynamics

Single-mode nonlinear envelope equation:

$$\dot{a}(t) = \left(-i\Delta - \frac{\kappa}{2}\right) a - i\kappa_3 |a|^2 a + \sum_j \sqrt{\kappa_j}\, s_j e^{i\phi_j}$$

Definitions:

- $a(t)$: complex mode amplitude
- $\Delta = \omega - \omega_\Psi$: detuning
- $\kappa = \sum_j \kappa_j + \kappa_{\text{int}}$: total linewidth
- $\kappa_3 > 0$: Kerr (Duffing) nonlinearity
- $s_j e^{i\phi_j}$: coherent input at port j

A.2 Constant-power constraint

For two symmetric ports:

$$|s_1| = |s_2| = s$$

Total injected power:

$$P_{\text{tot}} = |s_1|^2 + |s_2|^2 = 2s^2 = \text{constant}$$

Only control variable:

$$\Delta\phi = \phi_2 - \phi_1$$

A.3 Effective coherent drive

For $\kappa_1 = \kappa_2 = \kappa_e$:

$$S(\Delta\phi) = \sqrt{\kappa_1}s_1 e^{i\phi_1} + \sqrt{\kappa_2}s_2 e^{i\phi_2} = 2\sqrt{\kappa_e}s\cos\left(\frac{\Delta\phi}{2}\right)$$

Effective power:

$$|S(\Delta\phi)|^2 \propto \cos^2\left(\frac{\Delta\phi}{2}\right)$$

A.4 Steady-state bistability condition

Steady-state amplitude $A = |a|$ satisfies:

$$\left[\left(\Delta + \kappa_3 A^2\right)^2 + \left(\frac{\kappa}{2}\right)^2\right] A^2 = |S(\Delta\phi)|^2$$

Bistability exists when:

$$\frac{\partial|S|^2}{\partial A^2} < 0 \quad \text{over a finite interval}$$

A.5 Hierarchy of scales

Required inequalities:

$$\omega_\Psi \gg \kappa \gg J \gg \Gamma_\varphi$$

and independently:

$$\kappa_3 A^2 \lesssim \kappa$$

A.6 Resonant non-additivity observable

Definition:

$$\Delta R(\omega, \Delta\phi) = R_{12}(\omega, \Delta\phi) - [R_1(\omega) + R_2(\omega)]$$

Requirements:

$$\Delta R \neq 0 \text{ only if } |\omega - \omega_\Psi| \lesssim \kappa$$

$$\Delta R \to 0 \quad \text{as} \quad |\omega - \omega_\Psi| \gg \kappa$$

A.7 Phase-noise model

Relative phase with noise:

$$\Delta\phi(t) = \Delta\phi_0 + \xi_\phi(t)$$

Noise statistics:

$$\langle \xi_\phi(t)\xi_\phi(t')\rangle = 2D_\phi\delta(t - t')$$

Dephasing rate:

$$\Gamma_\varphi \propto D_\phi$$

A.8 Numerical integration constraints

Time step:

$$\Delta t \ll \kappa^{-1}$$

Phase sweep rate:

$$\left|\frac{d\Delta\phi}{dt}\right| \ll \kappa$$

Integration must be continuous in time. No state reinitialization allowed.

A.9 Minimal falsification condition

Under:

- $\kappa_3 > 0$ independently verified
- $P_{\text{tot}} = \text{constant}$
- coherent phase control
- near-resonant operation

If:

$$\frac{\partial A}{\partial \Delta\phi} = 0 \quad \text{and} \quad \Delta R = 0$$

then the Ψ-resonant implementation hypothesis fails.

B Appendix closure

This appendix is sufficient to:

- implement the dynamics,
- simulate the dynamics,
- diagnose correct behavior,
- falsify incorrect implementations.

No additional equations are required.